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SUBMISSION OF SUBSTITUTE SPECIFICATION

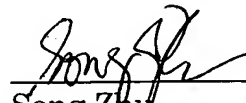
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Sir:

Attached are a Substitute Specification and a marked-up copy of the original specification. I certify that said substitute specification contains no new matter and includes the changes indicated in the marked-up copy of the original specification.

Respectfully submitted,

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INTERNAL COMBUSTION ENGINE COMPRISING A GAS CONVEYING SYSTEM AND OPERATING METHOD THEREFOR

The invention relates to an internal combustion engine comprising a gas conveying system and to an operating method therefor.

US Patent 6,094,909 has disclosed an internal combustion engine having a gas conveying system. The gas conveying system comprises a turbine which can be driven by an airstream and a pump which is driven by the turbine and can deliver gas into the exhaust system. This gas conveying system is used when the internal combustion engine is starting up, in order to feed secondary air to the exhaust system so that unburnt fuel constituents can be oxidized. The heat of combustion released is used to heat the exhaust-gas purification system, which is therefore ready to operate more quickly. The turbine is driven by an airstream that is caused by a pressure gradient present across a throttle element in the intake line. However, secondary air is only supplied to a sufficient extent when the turbine or the pump which it drives has reached a sufficient rotational speed, which takes a certain amount of time, and consequently the gas conveying system cannot provide secondary air immediately after the internal combustion engine has been started up. The gas conveying system has no further functions apart from the delivery of secondary air when the internal combustion engine is starting up.

By contrast, it is an object of the invention to provide an internal combustion engine comprising a gas conveying system and an operating method therefor which allow the internal combustion engine to operate with low emissions and allow good utilization of the gas conveying system.

According to the invention, this object is achieved by an internal combustion engine has a throttle element (6), an intake line (2), in which the throttle element (6) is arranged, an exhaust system (3, 4, 5), and an air conveying system. The air conveying system includes a turbine (7) and a pump (8). The turbine (7) has a turbine inlet line (9) and a turbine outlet line (10), and is driven by an air stream flowing through the turbine outlet line (10). The pump (8) is driven by the turbine (7) and includes a pump inlet line (11) and a pump outlet line (12) via which air delivered by the pump (8) is fed to the exhaust system (3, 4, 5). During engine start-up the air conveying system sets the quantity of injected fuel as a function of the delivery capacity of the pump (8). This object can also be achieved by a

method that includes the steps of, during engine start-up, feeding air delivered by the pump (8) to the exhaust system (3, 4, 5) and setting the quantity of fuel injected as a function of the delivery capacity of the pump (8).

The internal combustion engine according to the invention is distinguished by the fact that when the internal combustion engine is being started up, the quantity of fuel injected into it can be set as a function of the delivery capacity of the pump. It is preferable for fuel to be injected only once a minimum delivery capacity of the pump has been reached, so that the start of fuel injection is dependent on the delivery capacity of the pump. The result of this is that secondary air can be added to the exhaust system at sufficient quantities with the aid of the pump when the fuel injection begins, in order to allow after-oxidation of unburnt fuel residues. After-oxidation converts incompletely burnt fuel by oxidation. The heat of the reaction which is released quickly heats the exhaust-gas purification system to its operating temperature, in particular downstream of the point at which secondary air is added. Consequently, effective exhaust-gas purification can be achieved quickly. In particular, the level of harmful hydrocarbon emissions (HC emissions) can be reduced during the starting phase. By contrast, if the beginning of fuel injection is not matched to the delivery capacity of the pump and, for example, fuel is injected into the combustion chambers of the internal combustion engine before the pump has reached a minimum delivery capacity, the atmospheric oxygen required as a reaction partner for after-oxidation of unburnt fuel in the exhaust system is not present in sufficient quantities, and consequently relatively large quantities of HC are emitted. On the other hand, if too little fuel is injected in relation to the delivery capacity of the pump, the air/fuel ratio (λ) in the exhaust system required for after-oxidation is too high, and after-oxidation likewise cannot take place. This leads to late light-off of the exhaust-gas catalytic converters, with the result that pollutants are emitted for a relatively long period of time.

In one configuration of the invention, the turbine can be driven by a part-stream of the combustion air taken in by the internal combustion engine via the intake line, the part-stream being produced by a pressure gradient which is present across the throttle element. This measure makes it possible to dispense with the need for additional units to drive the turbine of the gas conveying system.

In a further configuration of the invention, when the engine is starting up, the speed of the internal combustion engine can be set before the fuel injection commences, by actuation of the internal combustion engine or by actuation of an auxiliary unit assigned to the internal combustion engine. It is preferable for the speed of the internal combustion engine to be increased at the beginning of the engine start-up operation. This makes it possible to quickly empty the induction pipe region by the internal combustion engine and to rapidly lower the induction pipe pressure. Consequently, the mass of air sucked in per intake section is rapidly reduced, so that an air/fuel ratio which is favorable for operation of the internal combustion engine and for after-oxidation can be set when the fuel injections begin. If the turbine of the gas conveying system is driven by the pressure drop which is present across the throttle element in the induction pipe, moreover, the pump rapidly reaches a sufficient delivery capacity as the result of the measure according to the invention. Consequently, sufficient quantities of secondary air can be delivered into the exhaust system even at a very early stage in the starting phase, with the result that in turn effective exhaust-gas purification can be provided quickly.

In a further configuration of the invention, the throttle element in the intake line can be set as a function of a pressure in the intake line. In particular if the turbine of the gas conveying system is driven by the pressure drop that is present across the throttle element in the induction pipe, it is possible for the throttle element to be set in such a way according to the quantity of air taken in by the internal combustion engine that the turbine of the gas conveying system quickly reaches its rotational speed. Consequently, the pump likewise quickly reaches a sufficient delivery capacity.

In a further configuration of the invention, the turbine can be driven by an airstream which is generated by a gas conveying unit which is arranged in the turbine inlet line or in the turbine outlet line or is connected to the turbine inlet line or to the turbine outlet line. This measure allows the turbine to be run up to speed and therefore the pump to reach a sufficient delivery capacity independently of the differential pressure which is present across the throttle element in the intake line.

In a further configuration of the invention, the gas delivery unit is designed as an electrically driven gas conveying unit. The electrical driving of the gas conveying unit allows accurate actuation of this unit and therefore of the gas conveying system as a whole.

In a further configuration of the invention, the gas conveying unit is designed as an evacuable gas vessel arranged in the turbine outlet line. If the evacuated gas vessel is opened, air is sucked into the vessel via the turbine and the turbine is thereby driven. This requires virtually no auxiliary energy. Therefore, the measure according to the invention allows the gas conveying system to operate independently of the differential pressure across the throttle element in a simple way.

In a further configuration of the invention, the gas stream delivered by the pump can be set as a function of an air/fuel ratio in the exhaust system. The gas stream delivered is preferably set in such a way that conditions which are advantageous for the after-oxidation are established downstream of the point at which the secondary air is added. It is preferable for the setting to be such that a λ value of approximately 1.2 is established.

In a further configuration of the invention, the gas stream delivered by the pump can be fed to an exhaust manifold of the exhaust system and/or direct to a catalytic converter of the exhaust system. This allows secondary air to be made available to the exhaust-gas purification system at the location where conditions are favorable for after-oxidation to occur. When the internal combustion engine is starting up, it is preferable for the secondary air to be fed to the exhaust manifold. If the internal combustion engine is being operated under rich conditions after it has been started up, secondary air may be added on the entry side of a catalytic converter fitted in an underbody position in order to oxidize the unburnt exhaust-gas constituents.

In a further configuration of the invention, exhaust gas can be fed to the pump via the pump inlet line, and the exhaust-gas stream delivered by the pump can be fed to the intake line. As a result, the gas conveying system realizes exhaust-gas recirculation. Accordingly, in addition to supplying secondary air, which occurs predominantly in the starting phase, the gas conveying system also performs a further function and is therefore better utilized.

In a further configuration of the invention, a reduced-pressure vessel connected via the pump inlet line can be evacuated by the pump. The reduced pressure generated by the pump in the reduced-pressure vessel can be used to drive servo units. The gas conveying system therefore performs a further function and is better utilized.

The method according to the invention is distinguished by the fact that when the internal combustion engine is starting up, the quantity of fuel injected is set as a function of the

delivery capacity of the pump. It is preferable for the injection of fuel to begin when the pump has reached a minimum delivery capacity. This ensures that no unburnt fuel constituents enter the exhaust system without atmospheric oxygen being made available at the same time to after-oxidize these unburnt fuel constituents. Matching the quantity of fuel injected to the delivery capacity of the pump ensures a λ value which is optimum for after-oxidation in the exhaust manifold.

In one configuration of the method, when the engine is starting up and before the fuel injection begins, the throttle element is held predominantly closed and is only opened after the pump has reached a minimum delivery capacity. The result of this is that conditions which allow effective after-oxidation of unburnt fuel constituents are very quickly reached in the exhaust system.

In a further configuration of the method, the engine speed of the internal combustion engine is increased as it is starting up before the fuel injection begins. Increasing the starting speed of the engine allows the air which is present in the induction pipe to be sucked out quickly, so that λ values which are favorable both for internal combustion engine operation and in the exhaust system are very quickly established. The starting engine speed can be increased by reducing the compression work performed by the internal combustion engine. It is preferable for the throttling of the internal combustion engine to be relieved, i.e. for the exhaust valves to remain open for a certain period of time or completely during the compression stroke. Furthermore, it is advantageous for auxiliary units which are driven by the internal combustion engine to be switched off or decoupled.

In a further configuration of the method, the turbine, at least from time to time, is driven by an airstream which is delivered by a gas conveying unit which is arranged in the turbine inlet line or the turbine outlet line or is connected to the turbine inlet line or the turbine outlet line. This allows the turbine to be run up to speed quickly in the initial phase irrespective of the differential pressure across the throttle element in the intake line and therefore allows secondary air to be delivered by the pump very quickly. The gas conveying unit is preferably formed by an electrically operated pump or by a pressure vessel or reduced-pressure vessel.

In a further configuration of the method, the airstream delivered by the pump is set as a function of an air/fuel ratio in the exhaust system. The result of this is that conditions which are favorable for the desired further reactions are established and further reactions can

therefore proceed in the desired way. It is preferable for a λ value of 1.2 to be set in the exhaust manifold.

In a further configuration of the method, one of at least two addition points at which the airstream delivered by the pump is added to the exhaust gas is selected as a function of the operating state of the internal combustion engine. On account of the fact that secondary air can be fed to the exhaust system at at least two locations, it is possible to react flexibly to the conditions in the exhaust system, which depend primarily on the operating state of the internal combustion engine.

In a further configuration of the method, the airstream delivered by the pump cools a definable part of the exhaust system if a predeterminable threshold value for a temperature in the exhaust system is exceeded. With this configuration of the invention, the gas conveying system additionally performs a cooling function, with the result that it is better utilized, the exhaust system can be operated more reliably and there is no need for other forms of cooling measures.

In a further configuration of the method, the pump at least from time to time removes exhaust gas from the exhaust system and feeds it to the intake line. In this case, the exhaust-gas stream fed to the intake line is preferably set as a function of the operating state of the internal combustion engine. Consequently, the gas conveying system performs an exhaust-gas recirculation function, so that the exhaust-gas recirculation can be made independent of the pressure conditions in the exhaust system and in the intake system of the internal combustion engine. The exhaust-gas recirculation quantity can be set as required on account of being dependent on the operating state.

In a further configuration of the method, a reduced-pressure vessel assigned to the internal combustion engine is evacuated by the pump via the pump inlet line in order to operate a servo system operated by reduced pressure. This further function of the gas conveying system makes it possible to draw additional benefit from this system and also constitutes a simplification with regard to the components employed.

The text which follows provides a more detailed explanation of the invention on the basis of drawings and associated examples.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a schematic block diagram of an embodiment of the internal combustion engine according to the invention with gas conveying system.

Fig. 2 shows a schematic block diagram of a further embodiment of the internal combustion engine according to the invention with gas conveying system.

Fig. 3 shows a schematic block diagram of a further embodiment of the internal combustion engine according to the invention with gas conveying system.

Fig. 4 shows a schematic block diagram of a further embodiment of the internal combustion engine according to the invention with gas conveying system.

Fig. 5 shows a schematic block diagram of a further embodiment of the internal combustion engine according to the invention with gas conveying system.

DETAILED DESCRIPTION OF THE DRAWINGS

Fig. 1 illustrates an internal combustion engine 1, which is, by way of example, a four-cylinder reciprocating-piston engine with spark ignition, referred to below just as engine for short, with a gas conveying system, intake system and exhaust system. When it is operating, the engine 1 takes in air via the intake line 2 with a throttle element 6 arranged therein and discharges exhaust gas to the environment via the exhaust manifold 3 and the exhaust pipe 4 connected to it. A catalytic converter 5 for purifying the exhaust gas is arranged in the exhaust pipe 4. The catalytic converter is in this case designed as a starting catalytic converter arranged close to the engine. The engine 1 is assigned a gas conveying system which comprises a turbine 7 and a pump 8. The pump 8 can be driven via a drive shaft of the turbine 7. A turbine inlet line 9 is connected to the turbine 7 on the inlet side, and a turbine outlet line 10 is connected to the turbine 7 on the outlet side. In each case the other end of the lines 9, 10 is connected to the intake line 2, upstream or downstream, respectively, of the throttle element 6, so that the turbine 7 is connected in parallel with the throttle element. The airstream delivered by the turbine 7 can in this case be controlled by a controllable valve 20 in the turbine outlet line 10. A pump inlet line 11, which is in communication with the environment, is connected to the pump on the entry side. A pump outlet line 12, which

branches off to form the addition points 13, 14 in the exhaust manifold 3 and in the exhaust pipe 4, respectively, is connected to the pump on the outlet side.

Furthermore, the engine 1 is assigned an injection system, not indicated in more detail, for injecting fuel, either directly into the combustion chambers of the engine 1 or into the inlet region of the individual cylinders. Moreover, the engine 1 has an engine control unit (not shown) for controlling or regulating operation of the engine 1 and the systems assigned to the engine 1. For this purpose, various sensors and measurement pick-ups (not shown), such as for example pressure sensors, an air mass flowmeter in the intake line 2 and exhaust-gas and temperature sensors in the exhaust pipe 4, are arranged in the intake system and in the exhaust system. The signals from the sensors are recorded and evaluated by the engine control unit. Moreover, the engine 1 is assigned a starter (not shown), operation of which initiates the starting operation and maintains the starter until the engine is operating independently.

The mode of operation of the installation illustrated in Fig. 1 is explained below.

In a first field of use, the gas conveying system is used to achieve low-emission starting or warming-up of the engine 1. For this purpose, it is crucial that the catalytic converter 5 arranged in the exhaust pipe 4 be able to operate with sufficient efficiency, i.e. at what is known as its light-off temperature, sufficiently quickly. For this purpose, after a certain instant in the starting operation, the engine is operated with a rich air/fuel ratio, and the reducing constituents in the rich exhaust gas obtained are burnt by after-oxidation upstream of the catalytic converter 5. In the text which follows, the air/fuel ratio of the mix fed to the engine 1 is referred to as engine λ or λ_E . The heat of combustion which is released during the after-oxidation heats the catalytic converter 5, so that the catalytic converter 5 can quickly perform its purification function. As a result of secondary air being supplied, the exhaust gas reaches the oxygen content required for the after-oxidation to proceed. The supply of secondary air is effected by the pump 8 driven by the turbine 7. Actuation of a switching unit (not shown) in the pump outlet line 12 opens up the addition point 13 in the exhaust manifold 3 for the addition of secondary air and blocks the addition point 14. The pressure drop which is present across the throttle element 6 and is caused by the flow of the air taken in by the engine 1 is used to drive the turbine. This pressure drop acts across the turbine inlet line 9 and

the turbine outlet line 10 and therefore causes air to flow across the turbine 7, thereby driving the turbine 7 and the pump 8 coupled to it.

A precondition for the after-oxidation to take place is that a combustible mixture be present. Therefore, for low-emission starting of the engine, it is important to match the fuel injection quantity and secondary air delivery. The aim is for the after-oxidation to commence as early as possible when starting up the engine 1.

According to the invention, during the starting operation the quantity of fuel injected is set as a function of the delivery capacity of the pump 8. It is preferable for no fuel to be injected initially when the starting operation begins, since at this instant the pump 8 is not yet delivering any secondary air. The reason for this is that the pressure drop across the throttle element 6 is not initially present or is too low. Since the speed of the engine 1, at typically approximately 200 rpm, is relatively low during the starting operation, a pressure drop across the throttle element is built up relatively slowly. To accelerate the build-up of pressure, the throttle element is set as a function of the reduced pressure which is present in the intake line 2 downstream of the throttle element 6. It is preferable for the throttle element to be completely closed in the absence of reduced pressure during the starting operation. This is the case right at the beginning of the starting operation. The result of this is that the air in the line volume between throttle element 6 and air inlet of the engine cylinders is rapidly sucked out by the engine. Consequently, a differential pressure across the throttle element 6 is quickly built up, and accordingly the turbine 7 quickly reaches its rotational speed and the pump 8 delivers secondary air correspondingly quickly.

The injection of fuel preferably only begins when the pump 8 has reached a minimum delivery capacity, which can be determined, for example, with the aid of a rotational speed sensor at the pump 8. The period of time from the beginning of starter actuation to the beginning of fuel injection can advantageously also be set in a time-controlled fashion. In this case, it is possible, for example, to make use of a table stored in the engine control unit, in which the periods until the fuel injection begins are stored. In this case, it is additionally possible to take account of the coolant temperature of the engine 1 or the ambient temperature.

The quantity of fuel injected per unit time is preferably set in such a way that an engine λ of approximately $\lambda_E = 0.8$ results. Therefore, an ignitable mixture is present in the combustion

chambers of the engine 1, and the engine 1 can continue to operate without starter assistance. When this independent engine running begins, the engine speed, the intake air quantity and the pressure drop across the throttle element 6 rise. In accordance with the setting as a function of reduced pressure, the throttle element 6 is opened when a predeterminable reduced-pressure value is reached. The quantity of secondary air delivered into the exhaust manifold 3 by the pump 8 is limited with the aid of the setting valve 20 in the turbine exhaust line 10 in such a way that conditions which are favorable for after-oxidation result in the exhaust manifold 3. The secondary air quantity is preferably set in such a way that an air/fuel ratio, also referred to below as exhaust-gas λ or λ_{EG} , of approximately $\lambda_{EG} = 1.2$ is set for the exhaust gas.

The time required to deliver a sufficient quantity of secondary air can be shortened still further if the starting speed of the engine 1 is increased during the starter operation. According to the invention, this is achieved by reducing the compression work performed by the engine 1. With a variable compression ratio, this is reduced in the starter phase of the starting operation. Furthermore, it is advantageous to relieve the throttling of the engine 1 by opening the outlet valves in the compression stroke. It is also advantageous to temporarily decouple auxiliary units which are driven by the engine 1. By way of example, it is possible to decouple a generator or a coolant pump. This reduces the mechanical power loss from the engine 1 and increases the engine speed during starter operation.

After stable and independent engine running and the light-off temperature of the starting catalyst 5 have been reached, the starting operation can be considered to have ended and the addition of secondary air to the exhaust manifold 3 is concluded. The ending of the addition of secondary air can be effected by closing the setting valve 20 or closing a switching device (not shown) in the pump outlet line 12.

In a further field of use, the gas conveying system is employed to reduce emissions during rich operation of the engine 1 outside the starting operation, for example during acceleration or under full load. Under these conditions, a pressure drop which is sufficient to operate the turbine 7 is present across the throttle element. In this application of the gas conveying system, the pump 8 passes secondary air into the exhaust gas at the addition point 14 on the entry side of a catalytic converter 5 which is in this case preferably arranged remote from the engine. In the process, an exhaust-gas λ of approximately $\lambda_{EG} = 1.0$ is set. Under these

conditions, reducing exhaust-gas constituents are oxidized by the catalytic converter 5 and the level of pollutants is reduced even during acceleration or full-load operation.

In a further application area, the gas conveying system is used to cool part of the exhaust system. By way of example, the pump 8 can be used to blow relatively cool ambient air into the air gap of a catalytic converter housing or exhaust manifold with air gap insulation. This function of the gas conveying system is preferably activated when a determining temperature in the exhaust system is exceeded. This prevents the exhaust system from being overheated or damaged and maintains the function of components which have a purifying action.

Fig. 2 diagrammatically depicts the arrangement of the engine 1 and the gas conveying system in a further preferred embodiment. The designation of functionally equivalent components corresponds to that employed in Fig. 1. In addition to the embodiment illustrated in Fig. 1, the gas conveying system is in this case assigned a further gas conveying unit, which is designed as an electrically driven air pump 15 which is connected to a branch of the turbine inlet line 9. Moreover, a shut-off valve 21, which can be used to shut off the connection to the intake line 2 upstream of the throttle element 6, is provided in the turbine inlet line 9. The turbine 7 can be run up to speed more quickly with the aid of the air pump 15 when the engine 1 is starting up. For this purpose, at the beginning of starter operation, the shut-off valve 21 is closed, the valve 20 is opened and the air pump is switched on. Therefore, air is delivered via the turbine 7 virtually as soon as the starting operation begins. Consequently, a quantity of secondary air which is sufficient for after-oxidation can be fed to the exhaust manifold 3 after just a short time irrespective of the build-up of differential pressure across the throttle element 6, and the fuel injection is performed in the same way as in the embodiment shown in Fig. 1. When a sufficient differential pressure has been built up across the throttle element 6, the air pump is switched off and the shut-off valve 21 is opened. The turbine 7 is then driven by the airstream flowing through the lines 9, 10, which is caused by the differential pressure across the throttle element 6. All the further functions of the gas conveying system are present in the same way as in the embodiment shown in Fig. 1.

Fig. 3 diagrammatically depicts the arrangement of the engine 1 and the gas conveying system in a further preferred embodiment. Functionally equivalent components are designated by the same references as in Fig. 1. In addition to the embodiment illustrated in Fig. 1, the gas conveying system is in this case assigned a further gas conveying unit, which

is designed as an evacuable gas vessel 16 which is arranged in a secondary branch of the turbine outlet line 10. The gas vessel can be shut off on the inlet side and the outlet side by a shut-off valve 22 and 23, respectively. The turbine 7 can be run up to speed more quickly with the aid of the evacuated gas vessel 16 during starting of the engine 1. For this purpose, when the starter operation begins, the shut-off valve 22 is opened on the inlet side of the evacuated gas vessel 16. The valves 20 and 23 remain closed. Therefore, air is conveyed into the evacuated gas vessel 16 via the turbine 7 virtually as soon as the starting operation begins. Consequently, a quantity of secondary air which is sufficient for after-oxidation can be fed to the exhaust manifold 3 after a short time irrespective of the build-up of differential pressure across the throttle element 6, and the fuel injection is performed in the same way as in the embodiment shown in Fig. 1. When a sufficient differential pressure has been built up across the throttle element 6, the valve 20 is opened and the valve 22 is closed. The turbine 7 is then driven by the airstream through the turbine inlet line 9 and the branch of the turbine outlet line 10 provided with the valve 20. The airstream is in this case produced by the differential pressure across the throttle element 6. To enable the turbine to be run up to speed quickly independently of the build-up of differential pressure across the throttle element 6, the gas vessel 16 must of course be of sufficient size. All the further functions of the gas delivery system are similar to the embodiment shown in Fig. 1. For renewed evacuation of the gas vessel 16, during normal engine operation the valve 23 is open and the valve 22 is closed. In particular at an engine operating point with a high subatmospheric pressure downstream of the throttle element 6, such as for example during overrun operation at a high engine speed, the gas vessel 16 can be evacuated sufficiently for a further starting operation.

Fig. 4 diagrammatically depicts the arrangement of the engine 1 and the gas conveying system in a further preferred embodiment. Functionally equivalent components are designated by the same references as those used in Fig. 1. With the embodiment illustrated in Fig. 4, it is possible to provide exhaust-gas recirculation in addition to the functions of the embodiment illustrated in Fig. 1. For this purpose, the gas delivery system has a branch, provided with a valve 24, of the pump inlet line 11, which branch is in communication with the exhaust pipe 4. That part of the pump inlet line 11 which is in communication with the environment can likewise be shut off by the valve 25 arranged therein. Furthermore, a branch of the pump outlet line 12 which leads into the intake line 2 downstream of the throttle element 6 is provided. This branch can likewise be shut off by the settable valve 26. if the gas

delivery system is not required to deliver secondary air, during normal engine operation the pump 8 can deliver exhaust gas into the intake line 2 at the addition point 18. For this purpose, the valve 24 is opened and the valve 25 is closed. The valve 26 is opened according to the exhaust-gas recirculation rate that is to be provided. The pump 8 is driven as described above by the airstream across the turbine 7 caused by the differential pressure across the throttle element 6. The embodiment shown in Fig. 4 can provide a higher exhaust-gas recirculation rate compared to standard exhaust-gas recirculation systems with passive exhaust-gas recirculation, in which the recirculated quantity of exhaust gas is determined by the differential pressure that is present between exhaust pipe and intake pipe. The reason for this is the active exhaust-gas delivery provided by the pump 8. All the further functions of the gas delivery system are present in the same way as in the embodiment shown in Fig. 1.

Fig. 5 diagrammatically depicts the arrangement of the engine 1 and the gas conveying system in a further preferred embodiment. Functionally equivalent components are designated by the same designations as in Fig. 1. Unlike in the embodiment illustrated in Fig. 1, the pump inlet line 11 is in this case connected to an evacuable gas vessel 17. A connection to the environment which can be shut off by a valve 27 is still present. If the gas conveying system is not required to deliver secondary air, the gas vessel can be evacuated by the pump 8 during normal engine operation. For this purpose, the valve 27 is closed. The air which is extracted from the gas vessel 17 can be fed to the exhaust gas via the pump outlet line 12 or can be released to the environment via a branch which is not shown. Servo systems which are operated by reduced pressure, are connected to the gas vessel 17 and are not indicated in more detail here can be operated by the reduced pressure generated in the gas vessel 17. All the further functions of the gas conveying system are still present in the same way as in the embodiment shown in Fig. 1.

With the embodiments of internal combustion engine and gas conveying system in accordance with the invention, it is possible, as illustrated, to provide low-emission operation of the internal combustion engine. The functions of the gas conveying system which are present in addition to the delivery of secondary air means that the gas conveying system is utilized better and that some components can be eliminated. In this context, it will be understood that modifications to the embodiments illustrated are possible within the scope of the invention by the use of additional lines or valves in the gas conveying system.